REMARKS

Reconsideration and the timely allowance of the pending claims, in view of the following remarks, are respectfully requested.

In the Final Office Action dated March 13, 2006, the Examiner rejected claims 1, 5, 21, and 25-26, under 35 U.S.C. §102(b), as allegedly being anticipated by Korenaga'721 (U.S. Patent Pub. No. 2002/0145721); rejected claims 1 and 21, under 35 U.S.C. §102(b), as allegedly being anticipated by Takashi '484 (D.E. 43 29 484)(incorrectly identified as "Tiedtke" in the Office Action); rejected claims 2 and 22-23, under 35 U.S.C. §103(a), as allegedly being unpatentable over Korenaga'721 in view of Kurosawa'716 (U.S. Patent Pub. No. 2002/0145716); rejected claims 3-4, under 35 U.S.C. §103(a), as allegedly being unpatentable over Korenaga'721 in view of Kurosawa'716 and Cutler '674 (U.S. Patent Pub. No. 2001/0029674); and rejected claims 9-10 and 27-28, under 35 U.S.C. §103(a), as allegedly being unpatentable over Korenaga'721 in view of Cutler '674 (U.S. Patent Pub. No. 2001/0029674).

Furthermore, in the Advisory Action of July 21, 2006, the Examiner asserted that the response to the rejection based on Takashi '484 was insufficient because the foreign search report indicated that the reference was relevant.

By this Amendment, independent claims 1 and 21 have been amended. Applicant submits that no new matter has been introduced. As such, claims 1-10 and 21-28 are currently presented for examination, of which claims 1 and 21 are independent.

Applicant respectfully traverses the prior art rejections, under 35 U.S.C. §102(b), §103(a) for the reasons presented below.

I. Prior Art Rejections Under 35 U.S.C. §102(b), §103(a).

As indicated above, amended independent claim 1 positively recites that the control unit is configured to produce a signal indicative of the control force based on ***the signal indicative of the difference*** between the desired mass position and the actual mass position. Furthermore, claim 1 also positively recites that the estimator unit is configured to calculate an estimated relation between ***the signal indicative of the control force*** and status information of the mass in which the status information comprises an indication of at least one of a position of the mass, a velocity of the mass, and an acceleration of the mass. Also, claim 1 positively recites a third input that receives a feed-forward signal indicative of the desired mass acceleration ***and adds the feed-forward signal to the signal indicative of the control force***. These features are amply supported by the embodiments described in the Specification. (*See*, Original Specification, par. **[00077]** – **[00079]**; **[00082]**-**[00084]**; **[00085]**-**[00097]**; FIGs. 2, 3).

In contrast to the Examiner's assertions, there is nothing in the asserted references that teach all of the elements recited in claim 1, including the features indicated above. In particular, the Korenaga '721 reference discloses three systems, a fine motion linear motor position servo system **125**, a movement feedback system **135**, and a feed-forward system **131**. (*See*, Korenaga '721, par. **[0053]**; FIG. 2).

Regarding the fine motion linear motor position servo **125**, the reference discloses that the calculating means **126**, which the Examiner alleged corresponds to the claimed "comparator," calculates a difference between a current target position of the stage as specified by a position profile producing means **122** and the current position of the stage **101** as measured by an interferometer **128**. (*See*, Korenaga '721, par. **[0054]**; FIG. 2). Korenaga '721 further discloses that correcting means **132**, adjusting means **133**, and electromagnetic amplifiers **134**, which the Examiner alleged corresponds to the claimed "control unit," are actually part of feed-forward system **131**

that produces a combined thrust proportional to the output of the acceleration profile producing means **123**. (*See,* Korenaga '721, par. **[0055]**; FIG. 2).

Applicant respectfully reminds the Examiner that the claim requires that the control unit is configured to produce a signal indicative of the control force ***based on the signal indicative of the difference between the desired mass position and the actual mass position***. Without conceding to the Examiner's characterizations of the claim nor the alleged teachings of the prior art, ***if*** the calculating means **126** (which the Examiner asserts corresponds to the claimed "comparator") calculates the claimed difference between a current target position of the stage and the current position of the stage **101** and ***if*** the combination of the correcting means **132**, adjusting means **133**, and electromagnetic amplifiers **134** *aka* feed-forward system **131** (which the Examiner alleged corresponds to the claimed "control unit") produces the claimed signal indicative of said control force – then the signal produced by the "control unit" is ***not based on the difference between the desired mass position and the actual mass position***, as required by claim 1.

That is, FIG. 2 clearly indicates that the ***only input*** of information to the Korenaga '721 correcting means **132**, adjusting means **133**, and electromagnetic amplifiers **134** (*aka* feed-forward system **131** and alleged claimed "control unit") is the acceleration profile producing means **123**. So, in other words, there is absolutely no supply of information from the output of the calculating means **126** (alleged claimed "comparator") to the correcting means **132**, adjusting means **133**, and electromagnetic amplifiers **134** (*aka* feed-forward system **131** and alleged claimed "control unit"). Thus, although the correcting means **132**, adjusting means **133**, and electromagnetic amplifiers **134** (*aka* feed-forward system **131** and alleged claimed "control unit") produces a combined thrust signal proportional to the output of the acceleration profile producing means **123**, it does not, in any way produce a signal indicative of the control force ***based on the signal indicative of the difference between said desired mass position and said actual mass position***, as supplied by the claimed comparator and as required by claim 1.

Moreover, Korenaga '721 discloses that the position profile producing means **122**, which the Examiner alleged corresponds to the claimed "estimator unit," generates the relationship between the time and the stage target position corresponding to that time. The reference further discloses that the acceleration profile producing means **123**, which the Examiner also alleged as corresponding to the claimed "estimator unit," generates a relationship between the time and the acceleration to be provided during that time. (*See,* Korenaga '721, par. [**0052**]; FIG. 2).

In so doing, the Korenaga '721 reference clearly fails to teach or suggest calculating the estimated relation between the signal indicative of the control force and status information of the mass in which the status information comprises an indication of at least one of a position of the mass, a velocity of the mass, and an acceleration of the mass, as required by claim 1. Specifically, both position profile producing means **122** and acceleration profile producing means **123** ***are inputs*** to the Korenaga '721 system (*i.e.*, fine motion linear motor position servo **125**, movement feedback system **135**, and feed-forward system **131**), so that they cannot, in any way, estimate a relation based on the control force signal generated by the control unit and the mass status information.

Along these lines, there is nothing in Korenaga '721 that remotely suggests a third input that receives a feed-forward signal indicative of said desired mass acceleration and adds the feed-forward signal to the signal indicative of the control force, as also required by claim 1. In other words, Korenaga '721 only discloses that feed-forward system **131** includes adjusting means **133** to adjust the attraction forces of electromagnets **108** and magnetic plate **107**. (*See,* Korenaga '721, par. [**0057**]; FIG. 2). As such, there is no desired mass acceleration feed-forward signal in Korenaga '721 that is added to the control force signal.

Applicant submits that the Takashi '484 reference fails to both cure the deficiencies of the Korenaga '721 reference identified above as well as teach each and every element of the claimed invention in its own right. To simplify matters, Applicant has submitted the British counterpart application, GB 2 270 998 (hereinafter "Takashi

'998"), to the German Takashi '484 reference (*see*, English abstract of Takashi '484 identifying GB 2 270 998 as the equivalent application).

Takashi '998 is directed to moving an object from an initial location to a destination in a driving apparatus, such as mobile robots and transportation systems. (*See,* Takashi '998, page 1, lines 3-8). Takashi '998 discloses inputting an acceleration set value **X"*** to a position command portion **1** that is integrated twice to generate a position command value **X*** that is, in turn, fed into position control portion **2**. (*See,* Takashi '998, page 2, lines 3-9; FIGs. 1, 2). Position control portion **2** generates a force F to be applied to control object **3**, mass estimation portion **4**, and maximum acceleration portion **4A**. (*See,* Takashi '998, page 2, lines 16-24; page 12, lines 1-24; FIGs. 1, 2).

With this said, Takashi '998 fails to teach the use of a first input that receives a signal based on a desired position of the mass, as required by claim 1. Takashi '998 only discloses that the first input that receives an "acceleration" set value **X"*** - not the recited desired ***position*** of the mass.

Moreover, Takashi '998 does not teach a third input that receives a feed-forward signal indicative of said desired mass acceleration and adds the feed-forward signal to the signal indicative of said control force, as required by claim 1. That is, Takashi '998 only teaches that the maximum acceleration value α_{max} – not the ***desired mass acceleration*** - from maximum acceleration portion **4A** is fed back – not ***fed forward*** – to an acceleration limiter **11**. Equally notable, the maximum acceleration value α_{max} is ***not added*** to the signal indicative of said control force – rather, it is supplied to the limiter **11** restricting the acceleration set value **X"***.

Applicant further submits that none of the remaining references, whether taken alone or in reasonable combination with Korenaga '721 or Takashi '998 teach the claimed combination of elements as recited in claim 1. For example, the Kurosawa'716 reference is directed to exposing a pattern onto a target locus that includes correction of the target locus. (*See,* Kurosawa'716, par. **[0007]**). As such, Kurosawa'716 merely

teaches the use of approximating a quadratic shape for data in a correction table via a least squares method. (*See,* Kurosawa'716, par. [**0059**]; FIG. 2).

The Cutler '674 reference is directed to non-contact, small displacement sensors to determine Abbe errors. (*See,* Cutler '674, par. [**0014**]). Along these lines, Cutler '674 merely teaches the use of a 4th-order low-pass profiling filter **78** and an adder **80**, which operates as a high-pass filter to form an acceleration feed forward signal. (*See,* Cutler '674, par. [**0036**], [**0038**]; FIG. 2).

For at least these reasons, Applicant submits that none of these references, whether taken alone or in reasonable combination, teach the claimed combination of elements recited by amended claim 1. Thus, claim 1 is patentable over the references. And, because claims 2-10 depend from claim 1, claims 2-10 are also patentable by virtue of dependency as well as for their additional recitations. Accordingly, Applicant requests the immediate withdrawal of the prior art rejections of claims 1-10.

Moreover, because independent claim 21 recites features that are similar to the patentable features discussed above regarding claim 1, claim 21 is also patentable for the same reasons presented above. And, because claims 21-28 depend from independent claim 21, claims 21-28 are patentable at least by virtue of dependency as well as for their additional recitations. Accordingly, Applicant requests the immediate withdrawal of the prior art rejections of claims 21-28.

II. Conclusion.

All matters shaving been addressed and in view of the foregoing, Applicant respectfully request the entry of this Amendment, the Examiner's reconsideration of this application, and the immediate allowance of pending claims 1-10 and 21-28.

Applicant's Counsel remains ready to assist the Examiner in any way to facilitate and expedite the prosecution of this matter. If any point remains in issue in which the Examiner feels may be best resolved through a personal or telephone interview, please contact the Undersigned at the telephone number listed below.

Please charge any fees associated with the submission of this paper to Deposit Account Number **03-3975**. The Commissioner for Patents is also authorized to credit any over payments to the above-referenced Deposit Account.

Respectfully submitted,

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G05B 19/407, G05D 13/62

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U1S S1881

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(54) Positioning system

(57) A positioning system eg for a robot includes a position command portion 1A which outputs a position command value for a controlled object 3, and a position control portion (2) which controls the controlled object so that its actual position value agrees with the position command value. The apparatus further includes a mass estimation portion 4 which estimates the mass or inertia value of the controlled object 4, a maximum acceleration computing portion 4A which computes the maximum,achievable acceleration α_{max} of the controlled object on the basis of the mass estimated by the mass estimation portion 4, and an acceleration limiter 11 which limits the second-order derivative of the position command value within the maximum acceleration α_{max}. The positioning system can eliminate unstable operation which may be involved in setting parameters of the position command portion or the position control portion.

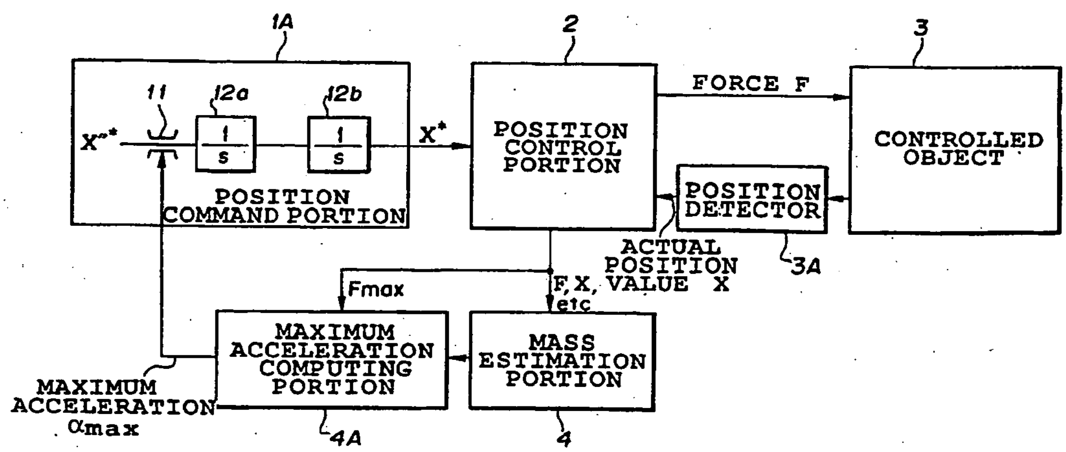


FIG. 2

GB 2 270 998 A

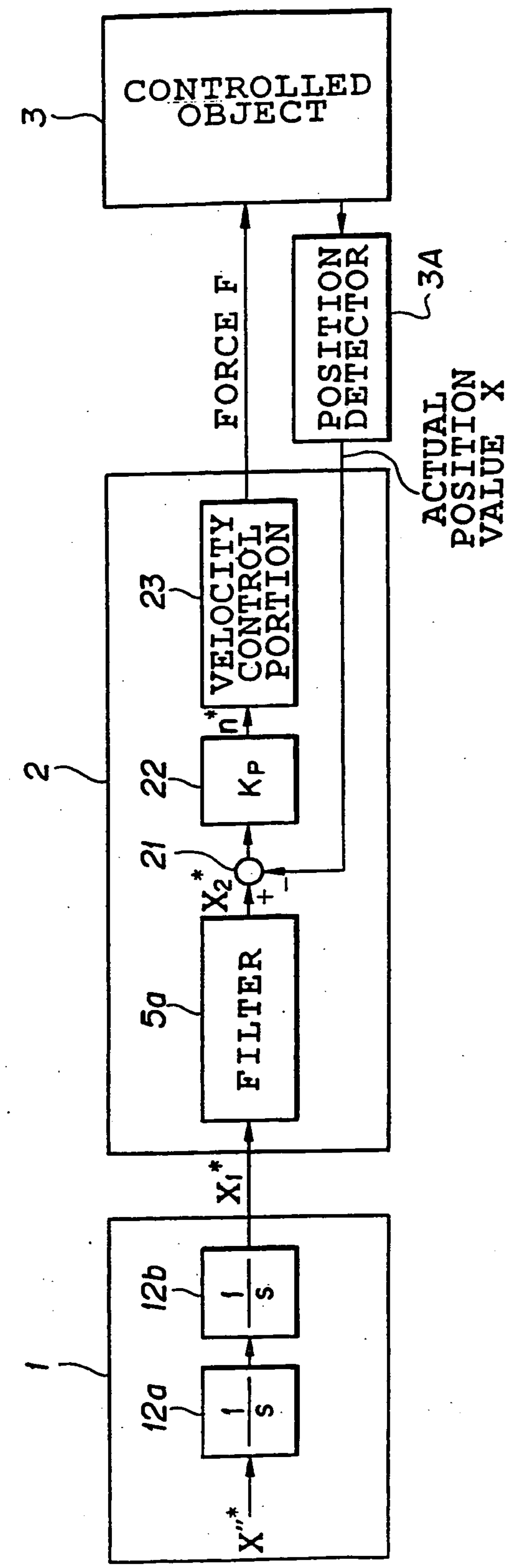

CONTROLLED OBJECT
3
FORCE F
POSITION DETECTOR
3A
ACTUAL POSITION VALUE X
VELOCITY CONTROL PORTION
23
n*
Kp
22
21
2
X2*
+
−
FILTER
5a
X1*
1/s
12b
1/s
12a
1
X''*

FIG. 1

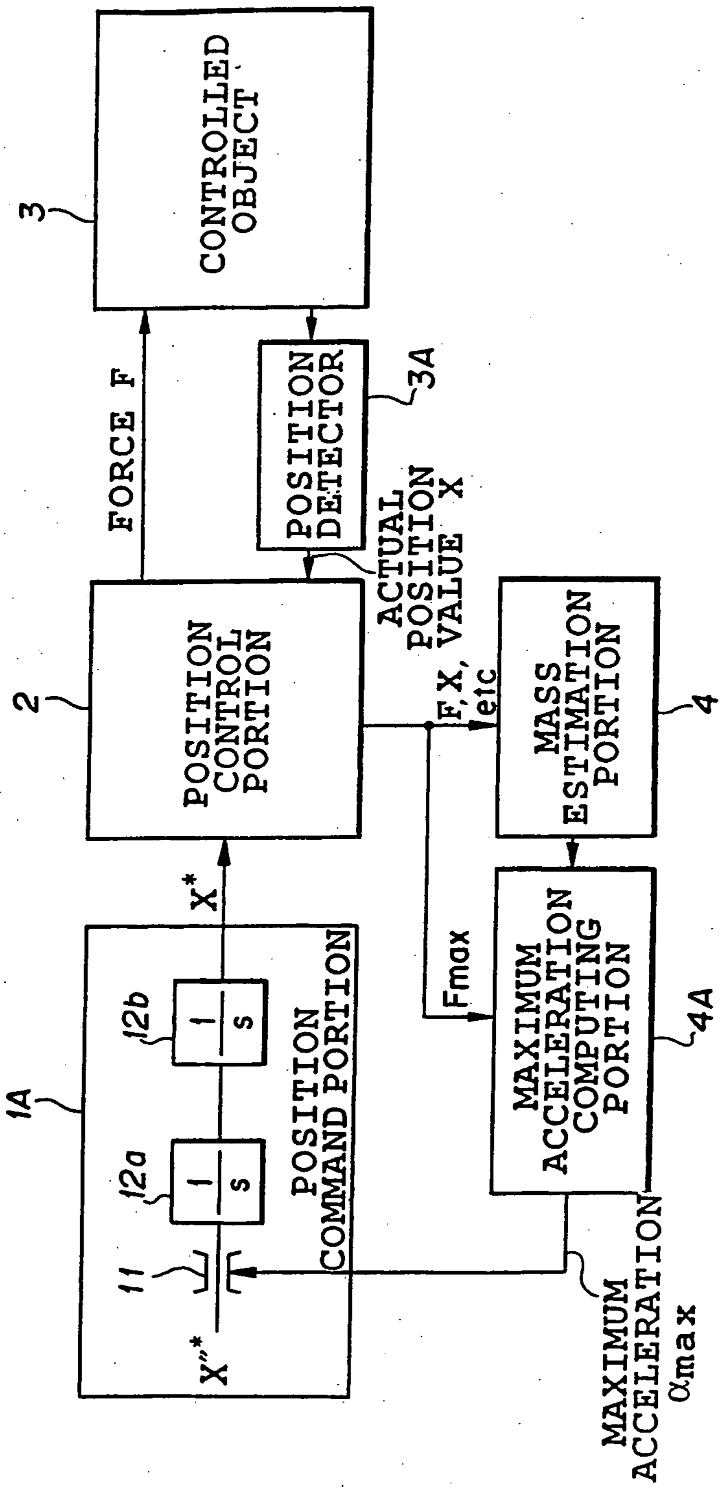
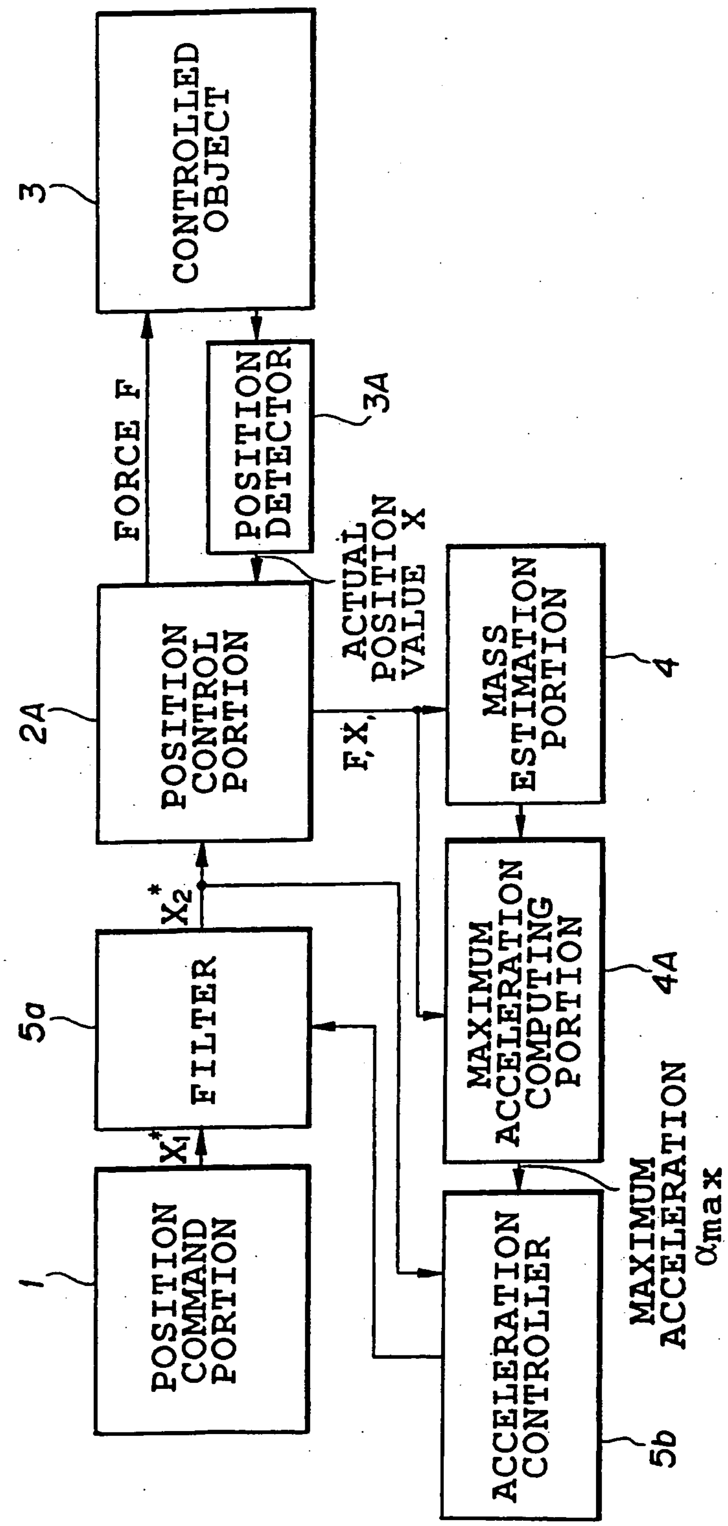

3
CONTROLLED OBJECT
FORCE F
POSITION DETECTOR
3A
ACTUAL POSITION VALUE X
2
POSITION CONTROL PORTION
F, X, etc
MASS ESTIMATION PORTION
4
Fmax
MAXIMUM ACCELERATION COMPUTING PORTION
4A
1A
12a
12b
11
1/s
1/s
X*
X''*
POSITION COMMAND PORTION
MAXIMUM ACCELERATION αmax

FIG. 2



3
CONTROLLED OBJECT
FORCE F
POSITION DETECTOR
3A
ACTUAL POSITION VALUE X
2A
POSITION CONTROL PORTION
F,X,
MASS ESTIMATION PORTION
4
5a
FILTER
X_2^*
MAXIMUM ACCELERATION COMPUTING PORTION
4A
1
POSITION COMMAND PORTION
X_1^*
ACCELERATION CONTROLLER
5b
MAXIMUM ACCELERATION
MAXIMUM ACCELERATION α_{max}

FIG.3

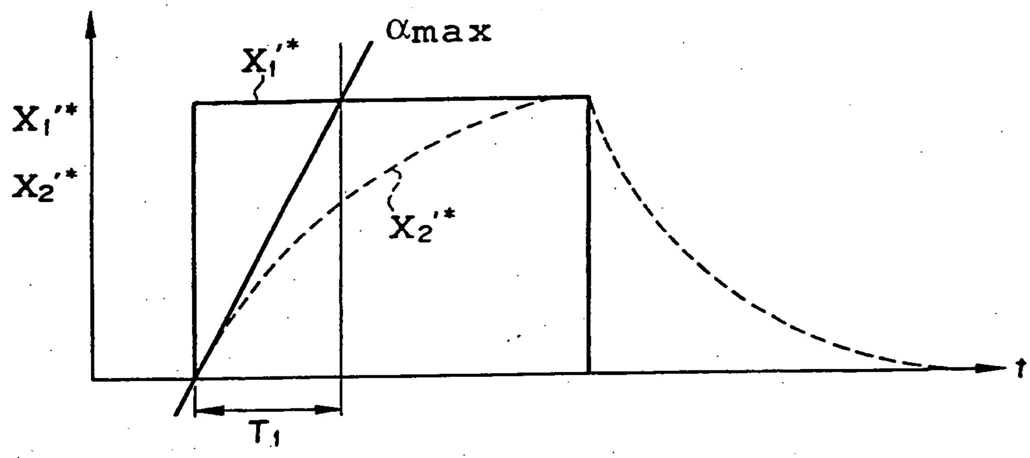


FIG.4

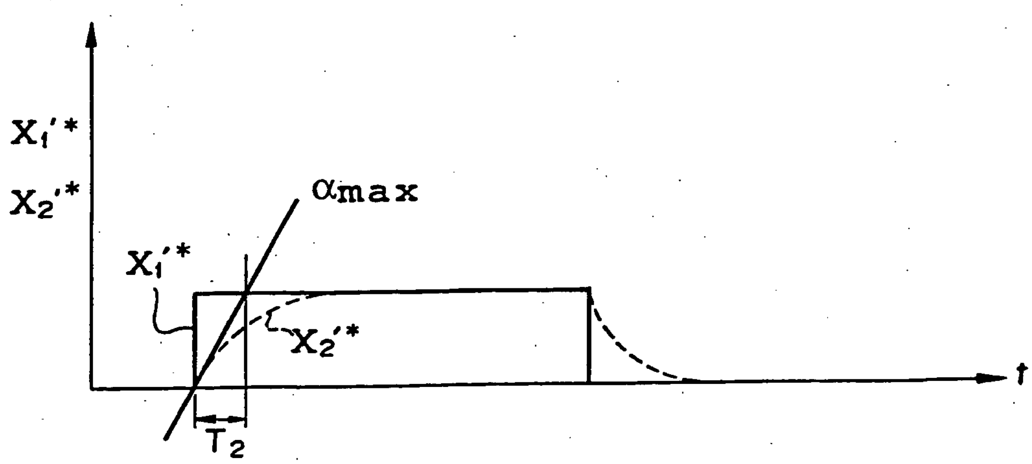
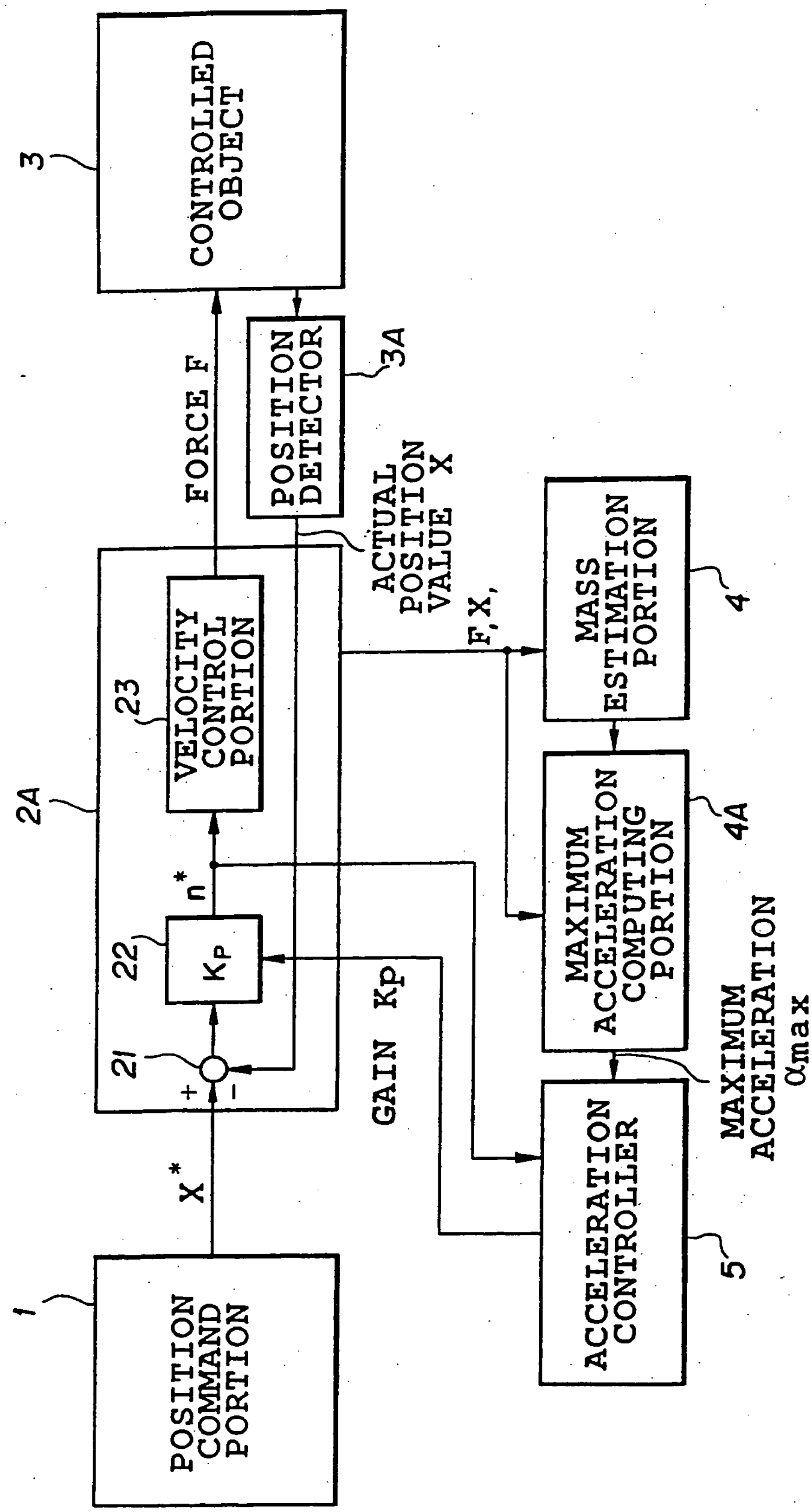


FIG.5



POSITION COMMAND PORTION
1
X^*
+
-
21
22
K_P
n^*
23
VELOCITY CONTROL PORTION
2A
FORCE F
CONTROLLED OBJECT
3
POSITION DETECTOR
3A
ACTUAL POSITION VALUE X
F,X,
MASS ESTIMATION PORTION
4
MAXIMUM ACCELERATION COMPUTING PORTION
4A
MAXIMUM ACCELERATION α_{max}
ACCELERATION CONTROLLER
5
GAIN Kp

FIG.6

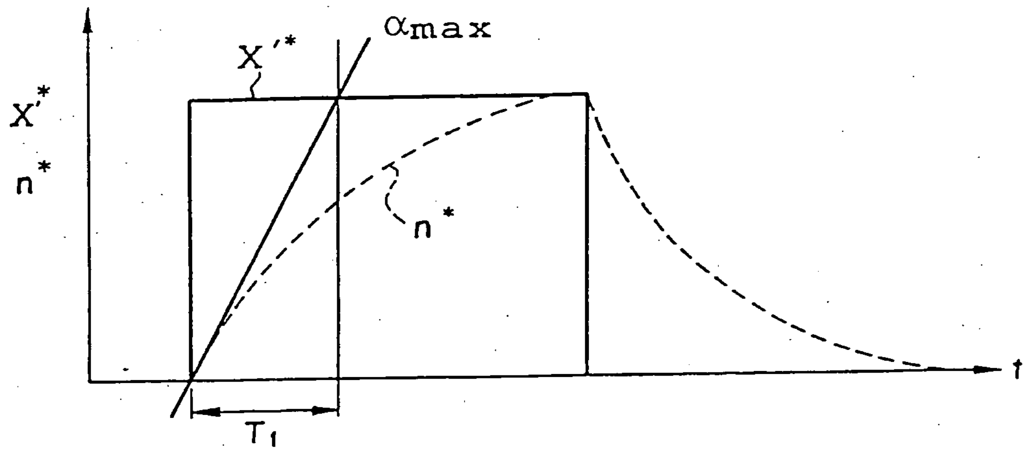


FIG. 7A

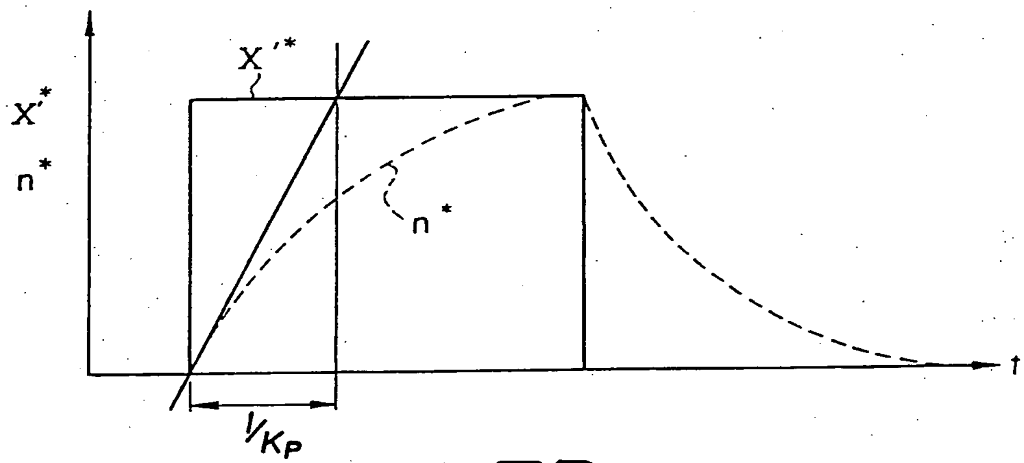


FIG. 7B

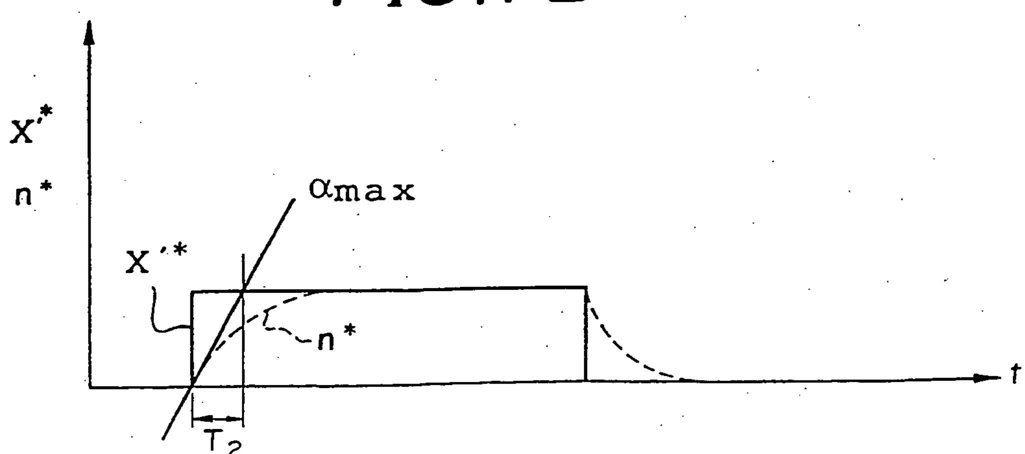


FIG. 8

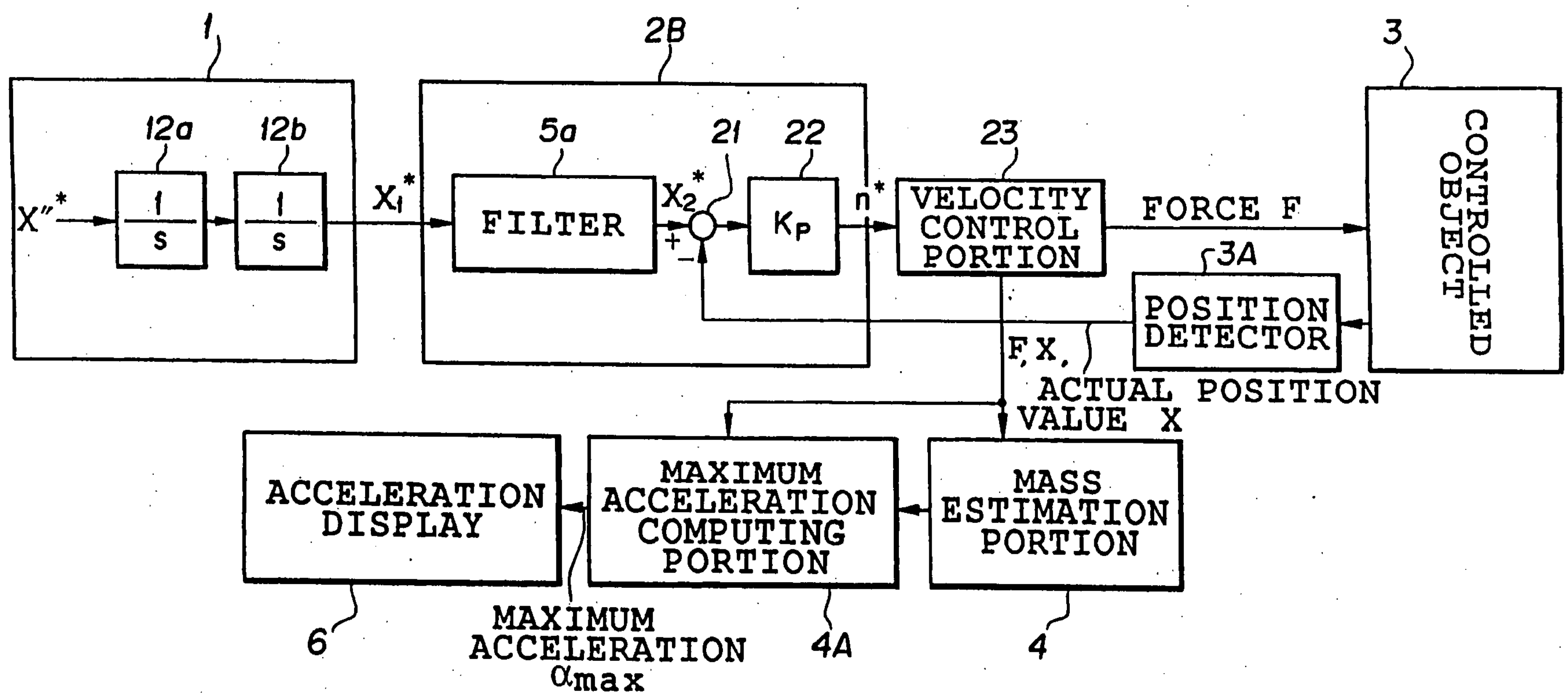

1
12a
12b
X"*
1/s
1/s
X1*
2B
5a
FILTER
X2*
21
+
−
22
KP
n*
23
VELOCITY CONTROL PORTION
FORCE F
3
CONTROLLED OBJECT
3A
POSITION DETECTOR
F, X,
ACTUAL POSITION VALUE X
ACCELERATION DISPLAY
MAXIMUM ACCELERATION COMPUTING PORTION
MASS ESTIMATION PORTION
6
MAXIMUM ACCELERATION αmax
4A
4

FIG. 9

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POSITIONING SYSTEM

The present invention relates to a positioning system that moves an object from an initial location to a destination location by using servo control in a driving apparatus like mobile robots, and various types of transporting systems.

In a positioning system which comprises a position command portion and a position control portion, it is generally required that the force or torque command to be provided to the position control portion be within its maximum output capacity. If a position command, which demands acceleration greater than the position control portion can provide, is applied to the position control portion, the actual position will not be able to follow the command. This results in large positional error, and may cause unstable operation such as overshoot or hunting.

Therefore, in the conventional positioning system, unstable operations as mentioned above may occur depending on the setting of parameters of the position command portion or the position control portion. When the unstable operations have actually occurred, the parameters must be readjusted to remove these unstable operations.

Fig. 1 is a block diagram showing a conventional positioning system.

In this figure, the acceleration set value X"* is successively integrated by integrators 12a and 12b in a position command portion 1, and a first position command value X_1* is generated therefrom. The first position command value X_1* is supplied to a position control portion 2 which drives a controlled object 3. During this process, the first position command value X_1* is converted to a second position command value X_2* by a filter 5a in the position control portion 2. In addition, a position detector 3A detects the position of the controlled object 3, and outputs the actual position value X.

An adder 21 outputs the difference between the second position command value X_2* and the actual position value X of the controlled object 3. A position adjuster 22 multiplies the difference by a gain Kp, and the product is outputted as a velocity command value n*. The velocity command value n* is inputted to a velocity control portion 23 which controls the controlled objects by the force F.

When the first position command value X_1* is provided which demands acceleration greater than the position control portion 2 can output, the actual position value X cannot follow the command

value, and hence unstable operations may result.

Methods for limiting acceleration in order to prevent the unstable operations may be as follows: Limiting the acceleration set value X"* in the position command portion 1; increasing the time constant of the filter 5a; and reducing the gain Kp of the position adjuster 22.

The best method of these is to reduce the acceleration set value X"* in the position command portion 1. A comparatively low cost system, however, may not have a position command portion that can freely limit the acceleration. In such a case, the time constant of the filter 5a must be increased as the second best method. In a system which has no such filter, the gain Kp of the position adjuster 22 must be reduced.

Thus, in conventional positioning systems, unstable operations may occur as soon as the set value of a parameter of the position command portion or the position control portion exceeds a certain limit which changes depending on the state of the controlled object. To prevent such unstable operations, the parameters must be readjusted. Such a readjustment usually takes a long time, and further readjustments are often required depending on operation conditions.

It is therefore an object of the present

invention to provide a positioning system which can eliminate unstable operations caused by the setting condition of parameters, and thus obviates tedious readjusting.

According to a first aspect of the present invention, there is provided a positioning system comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by the mass estimation means, and maximum force which can be provided by the position control means; and

acceleration limiting means for limiting the second-order time derivative of the position command value within the maximum acceleration

obtained by the maximum acceleration computing means.

According to a second aspect of the present invention, there is provided a positioning system comprising:

position command means for outputting a first position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by the mass estimation means, and maximum force which can be provided by the position control means;

smoothing means for smoothing the first position command value with regard to time, and outputting a second position command value; and

acceleration control means for limiting the

second-order time derivative of the second position command value within the maximum acceleration obtained by the maximum acceleration computing means.

Here, the acceleration control means may control a constant of the smoothing means in such a manner that the degree of smoothing is only emphasized.

The constant of the smoothing means may be reset to its initial value only when the input and output of the smoothing means agrees with each other.

The smoothing means may be a low-pass filter, and the constant of the smoothing means may be the time constant of the low-pass filter.

According to a third aspect of the present invention, there is provided a positioning system comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value, the

position control means including a position adjuster for obtaining a velocity command value by multiplying the difference between the position command value and the actual position value by a gain Kp, and a velocity control means for controlling the controlled object so that its actual velocity value agrees with the velocity command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by the mass estimation means, and maximum force which can be provided by the position control means; and

acceleration control means for limiting the first-order time derivative of the velocity command value outputted from the position adjuster within the maximum acceleration obtained by the maximum acceleration computing means.

The acceleration limiting means may control the gain Kp of the position adjuster in such a manner that the gain Kp is only reduced.

The gain Kp of the position adjuster may be reset to its initial value only when the position command value and the actual position value agrees with each other.

According to a fourth aspect of the present invention, there is provided a positioning system comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value, the position control means including a position adjuster for obtaining a velocity command value by multiplying the difference between the position command value and the actual position value by a gain Kp, and a velocity control means for controlling the controlled object so that its actual velocity value agrees with the velocity command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by the mass estimation means, and maximum force which can be provided by the

position control means; and

display means for displaying the maximum acceleration, or an acceleration and deceleration time which is computed on the basis of the mass and the maximum force which the position control means can provide.

According to the first to third aspects of the present invention, the force outputted from the position control means is limited within its maximum output value. As a result, the difference between the position command value and the actual position value of the controlled object does not exceeds a certain value. This prevents overshoot or hunting, thereby achieving stable operation. Furthermore, this makes it possible to eliminate an adjustment of parameters, or a readjustment of operation conditions when the operation conditions are changed.

According to the fourth aspect of the present invention, set values of parameters can be readily obtained from the maximum acceleration and the like which are displayed on the display means. Thus, the apparatus can be adjusted to an appropriate operation condition by only the first test operation, thereby simplifying the adjusting operation.

The above and other objects, effects,

features and advantages of the present invention will become more apparent from the following description of the embodiments thereof taken in conjunction with the accompanying drawings.

Fig. 1 is a block diagram showing a conventional positioning system;

Fig. 2 is a block diagram showing a first embodiment of a positioning system in accordance with the present invention;

Fig. 3 is a block diagram showing a second embodiment of the positioning system in accordance with the present invention;

Fig. 4 is a graph illustrating waveforms of first-order derivatives $X_1'^*$ and $X_2'^*$ and the maximum acceleration α_{max} during high acceleration and deceleration in the second embodiment shown in Fig. 3;

Fig. 5 is a graph illustrating waveforms of the first-order derivatives $X_1'^*$ and $X_2'^*$ and the maximum acceleration α_{max} during low acceleration and deceleration in the second embodiment shown in Fig. 3;

Fig. 6 is a block diagram showing a third embodiment of the positioning system in accordance with the present invention;

Figs. 7A and 7B are graphs illustrating waveforms of first-order derivatives $X_1'^*$ and

$X_2'^*$ and the maximum acceleration α_{max} during high acceleration and deceleration in the third embodiment shown in Fig. 6;

Fig. 8 is a graph illustrating waveforms of the first-order derivatives $X_1'^*$ and $X_2'^*$ and the maximum acceleration α_{max} during low acceleration and deceleration in the third embodiment shown in Fig. 6; and

Fig. 9 is a block diagram showing a fourth embodiment of the positioning system in accordance with the present invention.

The invention will now be described with reference to the accompanying drawings.

EMBODIMENT 1

Fig. 2 is a block diagram showing a first embodiment in accordance with the present invention. In Fig. 2, the reference numeral 1A designates a position command portion incorporating an acceleration limiter 11 which will be described later, in addition to the integrators 12a and 12b. The reference numerals 2 and 3 designate the position control portion and the controlled object, respectively, as in Fig. 1.

The reference numeral 4 designates a mass estimation portion newly added in this

embodiment. This mass estimation portion 4 estimates the mass or the inertia value of the controlled object 3 from the operation characteristic of the controlled object 3, such as the force F and the actual position value X fed by the position detector 3A, the force F and the velocity command value, the force F and the actual velocity n, the force F and the acceleration X", etc. The details of a method for estimating the mass or the inertia value is described in 3 "Instantaneous Speed Detection with Parameter Identification for ac Servo Systems", by K. Fujita, et al, IEEE Transactions on Industry Applications, Vol. 28, No. 4, July/August, 1992. The reference numeral 4A designates a maximum acceleration computing portion that computes the maximum acceleration α_{max} (or the maximum angular acceleration) on the basis of the estimated mass (or inertial value) and the maximum force F_{max} or torque which the position control portion 2 can provide, and supplies the maximum acceleration α_{max} to the acceleration limiter 11 in the position command portion 1A.

The acceleration limiter 11 limits the acceleration command value X"* inputted thereto so that the value X"* does not exceed the maximum acceleration value α_{max} fed from the mass

estimation portion 4. The position command portion 1A carries out the position command calculation on the basis of the output of the acceleration limiter 11.

According to the first embodiment, the second-order time derivative X*" of the position command value X* is limited within the maximum acceleration α_{max} by the acceleration limiter 11. Thus, the force F outputted from the position control portion 2 does not exceed the possible maximum output of the position control portion 2. This prevents an excessive position error, thereby achieving a stable operation.

Since the present embodiment limits only the acceleration command value X"* that would exceed the maximum acceleration α_{max}, the acceleration command value X"* smaller than the maximum acceleration α_{max} may be treated as in the conventional system.

EMBODIMENT 2

Fig. 3 shows a second embodiment in accordance with the present invention. This embodiment is substantially different from the conventional system in Fig. 1 in that the position control portion 2 in Fig. 1 is divided into the filter 5a and a position control portion 2A, and that the mass estimation portion 4 and an

acceleration controller 5b are added. Here, the filter 5a functions as a smoothing portion, and the acceleration controller 5b functions as an acceleration limiting portion. The position command portion 1 is the same as that of Fig. 1.

The acceleration controller 5b receives the maximum acceleration α_{max} from the maximum acceleration computing portion 4A and the second position command value X_2^* from the filter 5a, and provides the filter 5a with a signal for adjusting the time constant of the filter 5a.

More specifically, the acceleration controller 5b controls the time constant of the filter 5a so that the second-order time derivative of the second position command value X_2^* does not exceed the maximum acceleration α_{max} when the second-order time derivative is greater than α_{max}.

The time constant is handled as follows when the filter 5a is a discrete time-domain primary filter.

First, the filtering characteristic is expressed by the following equation (1).

$$X_2^*(i) = X_2^*(i-1) + \{X_1^*(i) - X_2^*(i-1)\}T_s/T_f \qquad (1)$$

where T_s is a sampling interval, and T_f is the

time constant of the filter 5a.

When the following expression (2) holds between the left-hand side associated with the second-order time derivative of the second position command value X_2* and the right-hand side (i.e., the maximum acceleration α_{max}), the time constant T_f of the filter 5a is calculated using equation (3b), into which $X_2*(i)$ obtained by equation (3a) is substituted, when expression (2) holds.

$$\{X_2*(i) - X_2*(i-1)\} - \{X_2*(i-1) - X_2*(i-2)\} > \alpha_{max} \qquad (2)$$

$$X_2*(i) = 2X_2*(i-1) - X_2*(i-2) + \alpha_{max} \qquad (3a)$$

$$T_f = \frac{X_1*(i) - X_2*(i-1)}{X_2*(i) - X_2*(i-1)} \cdot Ts \qquad (3b)$$

Once the time constant T_f of the filter 5a has been increased in the process of adjusting by the acceleration controller 5b, it is preferable that the time constant be not decreased again. This is because it is very likely that the maximum value α_{max} is exceeded during the deceleration when it has been exceeded during the acceleration. In addition, since the filter 5a is associated with position, it includes a delay proportional to its time constant when the

position is changing. Accordingly, decreasing the time constant T_f which has been once increased will decrease the delay in proportion thereto. In such a case, a deceleration operation, which coincides with the decrease in the time constant, will not be able to follow the position command value, and induces overshoot. Thus, it is preferable that the time constant T_f be only increased to maintain stable operation.

Figs. 4 and 5 illustrate relationships between the time, and the first-order time derivatives $X_1'^*$ and $X_2'^*$ of the first and second position command values X_1^* and X_2^*, and the maximum acceleration α_{max}, respectively. As shown in these figures, the time constants T_1 and T_2 ($T_1 > T_2$) of the filter required to obtain the same acceleration for different estimationvelocities are different.

More specifically, in order to limit the actual acceleration within the maximum acceleration α_{max}, the time constant T_f of the filter must be set at a rather large value T_1 in a high acceleration and deceleration range as shown in Fig. 4, but may be set at a rather small value T_2 in a low acceleration and deceleration range as shown in Fig. 5.

If the time constant T_f is set at T_1 in the case of Fig. 5, the operation will be unduly

delayed. An optimum time constant can always be achieved by returning the time constant T_f of the filter 5a to its initial value every time one cycle of operation has been completed, because the input and output of the filter 5a become usually identical by the operation.

The filter 5a may be a second- or third-order filter having an S-curve characteristic that makes the acceleration waveform as smooth as a character S.

When the first-order time derivative of the first position command value X_1^* changes stepwise, the filter computation defined by the following equation (4) makes it possible for the first-order time derivative of the second position command value X_2^* to change linearly, and the acceleration can be limited within the maximum acceleration α_{max} in this case.

$$dX_2^*/dt = \sqrt{2(X_1^* - X_2^*)\alpha_{max}} \qquad (4)$$

EMBODIMENT 3

Fig. 6 shows a third embodiment in accordance with the present invention. This embodiment comprises the mass estimation portion 4 and the maximum acceleration computing portion 4A as in Figs. 2 and 3. In addition, it comprises an acceleration controller 5 for

limiting acceleration. The acceleration controller 5 controls the gain Kp of the position adjuster 22 in the position controlling portion 2A on the basis of the velocity command value n* from the position adjuster 22 and the maximum acceleration α_{max} from the maximum acceleration computing portion 4A.

The acceleration controller 5 controls the gain Kp of the position adjuster 22, when the first-order time derivative of the velocity command value n* outputted from the position adjuster 22 exceeds the maximum acceleration α_{max}, so that the first-order time derivative falls within the maximum acceleration α_{max}.

The velocity command value n* is obtained in accordance with the following equation (5) in the discrete time system.

$$n^*(i) = \{X^*(i) - X(i)\}\ Kp \qquad (5)$$

Accordingly, the acceleration controller 5 computes n*(i) and Kp using the following equations (6) and (7) when $n^*(i) - n^*(i-1) > \alpha_{max}$.

$$n^*(i) = n^*(i-1) + \alpha_{max} \qquad (6)$$

$$Kp = n^*(i)/\{X^*(i) - X(i)\} \qquad (7)$$

Once the gain Kp has been reduced, it is usually preferable that the gain be not increased again for the same reason as described in the second embodiment of the present invention. Since the gain Kp of the position adjuster 22 functions in a manner similar to the time constant of a filter, the actual position value X during movement somewhat delays with regard to the position command value X*, and the delay is inversely proportional to the gain Kp. As a result, when the gain Kp which has once been decreased is increased again during the movement, the delay will reduce in inverse proportion. This makes it difficult for the deceleration to follow the position command value, and induces overshoot. Thus, the stable operation can be achieved only by decreasing the gain Kp rather than increasing it.

Figs. 7A and 7B illustrate relationships between the time, and the first-order time derivative X'* of the position command value X*, the velocity command value n*, and the maximum acceleration α_{max} in the high acceleration and deceleration range, and Fig. 8 illustrates those in the low acceleration and deceleration range. As shown in these figures, the gain Kp required to obtain the same acceleration for different velocities is different.

More specifically, the maximum slope of the velocity command value n*, when the first-order time derivative X'* takes a step change, is 1/Kp as shown in Fig. 7B. This maximum slope 1/Kp must not exceed the slope of the maximum acceleration α_{max}. In other words, in order to limit the actual acceleration within the maximum acceleration α_{max}, the gain Kp must be set at a rather small value $1/T_1$ in the high acceleration and deceleration range as shown in Figs. 7A and 7B, but may be set at a rather large value $1/T_2$ in the low acceleration and deceleration range as shown in Fig. 8, where $T_1 > T_2$.

When the gain Kp were set at $1/T_1$ in the case of Fig. 8, the operation would be unduly delayed. An optimum gain can always be achieved by returning the gain Kp to its initial value every time one cycle of operation has been completed, because the actual position X and the position command value X* become usually identical by the operation.

EMBODIMENT 4

Fig. 9 shows a fourth embodiment in accordance with the present invention. This embodiment is applied to the arrangement in which no information other than the velocity command value n* is available because the position

control portion 2 is divided into two separate portions, that is, a position control portion 2B comprising the adder 21 and the position adjuster 22, and a velocity control portion 23. The apparatus is substantially the same as that of Fig. 1 plus the mass estimation portion 4, the maximum acceleration computing portion 4A and an acceleration display portion 6.

The acceleration display portion 6 displays the maximum acceleration α_{max} (or maximum angular acceleration) computed by the maximum acceleration computing portion 4A.

In this embodiment, it is not required to limit the acceleration command X"* by the acceleration limiting portion as in the first embodiment shown in Fig. 2, to adjust the time constant of the filter 5a as in the second embodiment shown in Fig 3, or to control the gain Kp as in the third embodiment shown in Fig. 6. Accordingly, adjustment of parameters such as an acceleration parameter of the position command portion 1 is essential.

For this reason, the maximum acceleration α_{max} is displayed so that the set value of each parameter is specified.

More specifically, a test operation is carried out so that the maximum acceleration α_{max}, which is calculated by the acceleration computing

portion 4A, is displayed on the acceleration display portion 6. The maximum acceleration α_{max} displayed is used to set the acceleration parameter of the position control portion 1. Thus, a single test operation allows to determine the value of the parameter, and hence trial-and-error testing is unnecessary. As a result, the adjusting operation is simplified and carried out quickly.

The present invention has been described in detail with respect to various embodiments, and it will now be apparent from the foregoing to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and it is the intention, therefore, in the appended claims to cover all such changes and modifications as fall within the true spirit of the invention.

CLAIMS:

1. A positioning system characterized by comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by said mass estimation means, and maximum force which can be provided by said position control means; and

acceleration limiting means for limiting the second-order time derivative of the position command value within the maximum acceleration obtained by said maximum acceleration computing means.

2. A positioning system characterized by comprising:

position command means for outputting a first position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by said mass estimation means, and maximum force which can be provided by said position control means;

smoothing means for smoothing the first position command value with regard to time, and outputting a second position command value; and

acceleration control means for limiting the second-order time derivative of the second position command value within the maximum acceleration obtained by said maximum

acceleration computing means.

3. The positioning system as claimed in claim 2, characterized in that said acceleration control means controls a constant of said smoothing means in such a manner that the degree of smoothing is only emphasized.

4. The positioning system as claimed in claim 3, characterized in that the constant of said smoothing means is reset to its initial value only when the input and output of said smoothing means agrees with each other.

5. The positioning system as claimed in claim 3, characterized in that said smoothing means is a low-pass filter, and the constant of said smoothing means is the time constant of the low-pass filter.

6. A positioning system characterized by comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value, said position control means including a position adjuster for obtaining a velocity command value by multiplying the difference between the position command value and the actual position value by a gain Kp, and a velocity control means for controlling the controlled object so that its actual velocity value agrees with the velocity command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by said mass estimation means, and maximum force which can be provided by said position control means; and

acceleration control means for limiting the first-order time derivative of the velocity command value outputted from said position adjuster within the maximum acceleration obtained by said maximum acceleration computing means.

7. The positioning system as claimed in claim 6, characterized in that said acceleration

limiting means controls the gain Kp of said position adjuster in such a manner that the gain Kp is only reduced.

8. The positioning system as claimed in claim 7, characterized in that the gain Kp of said position adjuster is reset to its initial value only when the position command value and the actual position value agrees with each other.

9. A positioning system characterized by comprising:

position command means for outputting a position command value for a controlled object;

position detecting means for detecting the actual position of the controlled object, and for outputting an actual position value of the controlled object;

position control means for controlling force exerted on the controlled object so that the actual position value of the controlled object agrees with the position command value, said position control means including a position adjuster for obtaining a velocity command value by multiplying the difference between the position command value and the actual position value by a gain Kp, and a velocity control means for controlling the controlled object so that its

actual velocity value agrees with the velocity command value;

mass estimation means for estimating the mass of the controlled object;

maximum acceleration computing means for computing maximum acceleration of the controlled object on the basis of the mass which is estimated by said mass estimation means, and maximum force which can be provided by said position control means; and

display means for displaying the maximum acceleration, or an acceleration and deceleration time which is computed on the basis of the mass and the maximum force which said position control means can provide.

10. A positioning system including: position detecting means for detecting the actual position of an object; positioning means for moving the object to a required position; means for providing an indication of the mass of the object; and acceleration limiting means which uses said indication to control the maximum acceleration of the object produced by the positioning means.

11. A positioning system substantially as hereinbefore described with reference to Figures 2-9 of the accompanying figures.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
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Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES: WPI

Documents considered relevant following a search in respect of Claims :-
1-11

Categories of documents

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&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
A	EP 0293554 A2 (WESTINGHOUSE)	
A	EP 0087812 A (HITACHI)	
A	WO 91/13388 A (NRDC)	

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